

**ADVANCED COMPOSITES TECHNOLOGY
CASE STUDY AT NASA LANGLEY RESEARCH
CENTER**

by

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FOREWORD

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E. Timothy Oppelt, Director
National Risk Management Research Laboratory

ABSTRACT

This report summarizes work conducted at the National Aeronautics and Space Administration's Langley Research Center (NASA-LaRC) in Hampton, VA, under the U.S. Environmental Protection Agency's (EPA) Waste Reduction Evaluations at Federal Sites (WREAFS) Program. Support for this study was provided by the Strategic Environmental Research and Development Program (SERDP). SERDP is a cooperative effort between DoD, DOE and EPA to develop environmental solutions that enhance mission readiness in defense operations.

The purposes of the WREAFS Program are to identify new technologies and techniques for reducing wastes from process operations and other activities at Federal sites, and to enhance the implementation of pollution prevention/waste minimization through technology transfer. New techniques and technologies for reducing waste generation are identified through waste minimization opportunity assessments and may be further evaluated through joint research, development, and demonstration projects.

Under the Chesapeake Bay Agreement, NASA-LaRC is a member of the Tidewater Interagency Pollution Prevention Program (TIPPP). At NASA-LaRC, a technique for producing advanced composite materials without the use of solvents has been developed. This assessment was focused on the production of non-refractory composite materials and aircraft structures made from those materials.

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SECTION 1

INTRODUCTION

1.1 PURPOSE

This report summarizes work conducted at the National Aeronautics and Space Administration's Langley Research Center (NASA-LaRC) in Hampton, Virginia, under the U.S. Environmental Protection Agency's (EPA) Waste Reduction Evaluations at Federal Sites (WREAFS) Program. Support for this study was provided by the Strategic Environmental Research and Development Program (SERDP). SERDP is a cooperative effort between DoD, DOE and EPA to develop environmental solutions that enhance mission readiness in defense operations.

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Under the Chesapeake Bay Agreement, NASA-LaRC is a member of the Tidewater Interagency Pollution Prevention Program (TIPPP). At NASA-LaRC, a technique for producing advanced composite materials without the use of solvents has been developed. This assessment was focused on the production of non-refractory composite materials and aircraft structures made from those materials.

The prepregging process represents one of the first steps in the manufacture of composite materials. During prepregging, carbon-based fiber tow bundles are impregnated with a plastic polymer powder to produce towpreg materials, which can then be formed and finished into plastic composites. The new prepregging process evaluated in this report has the potential to reduce air emissions, solid

wastes, and hazardous wastes during the manufacture of prepreg materials. Currently, polymer powders are most commonly applied to fibers by dipping the fibers into a tank containing a polymer dissolved in an organic solvent. The organic solvents are then vaporized in drying ovens. The new process, evaluated at NASA Langley is a dry process that does not require the use of solvents for the production of towpreg. The purpose of this investigation was to examine the dry process for its potential to prevent pollution, as compared to a typical solvent-based process.

1.2 COMPOSITE USES AND TRADITIONAL MANUFACTURING METHODS

1.2.1 Uses and Methods of Producing Prepreg

The use of plastic composites has increased dramatically throughout the United States over the past 20 years. Composites are used extensively in automobiles, sporting equipment, electronic devices, and in many high-technology areas, including space travel and military equipment. Plastic composites exhibit more attractive mechanical properties than conventional materials, including superior elevated temperature qualities, higher strength-to-weight ratios, very low reactivity, and minimal degradation over time (e.g., no rust development, smooth surfaces which resist rust and scratching). The increasing use of composites is generally found in niches that were conventionally filled by metals, such as steel and aluminum, or other plastics.

One of the most significant steps in the manufacture of plastic composites is the process of combining continuous fiber tows with plastic resins to create prepreg materials, which can then be formed and finished. Two widely used methods of accomplishing the prepregging process include hot melt prepregging and solution prepregging. Solution prepregging is by far the most commonly used method; hot melt prepregging applications currently are very limited.

1.2.2 Hot Melt Prepregging

During hot melt prepregging, prepreg materials are manufactured by coating a heated resin onto a spread fiber tow. The plastic resin is heated first to reduce the viscosity as much as possible without damaging the structure of the resin. Hot melt prepregging is rarely used due to two primary limitations. The first limitation is that the viscosity of the plastic resin melt is generally quite high, which causes difficulty in achieving a smooth and even coating on the carbon tow. The second limitation arises from

the generally lower performance levels of the hot melt prepreg product, due to the uneven resin coating. These low performance levels can be attributed directly to difficulties experienced during the coating process.

Aside from the coating difficulties and performance limitations associated with the prepreg product, hot melt prepregging is an attractive process. The machinery required to perform hot melt prepregging is less complex than solution prepregging equipment. Environmentally, hot melt prepregging is a relatively innocuous process, as little to no organic solvents are consumed or emitted during operation. Minor amounts of volatile organic compound (VOC) emissions are possible during hot melt prepregging due to the escape of residual VOCs in the resin from resin manufacturing. These emissions are likely to be negligible in comparison to solution-based prepregging.

Hot melt prepregging may become a more attractive prepregging process as environmental regulations increasingly restrict the use of volatile solvents. Despite its simplicity and environmental advantages, however, it is unlikely that hot melt prepregging will gain acceptance without first overcoming its processing difficulties and product quality limitations.

1.2.3 Solution Prepregging

Solution prepregging is the most prevalent form of prepregging in use today. In one very common form of solution prepregging, the carbon fibers of the tow are spread and then dipped into a tank containing the polymer dissolved in a volatile solvent. The tow is then passed through a series of furnace sections to evaporate the solvents and fuse the polymer to the tow fibers. A schematic of the solution prepregging system is provided in Figure 1.

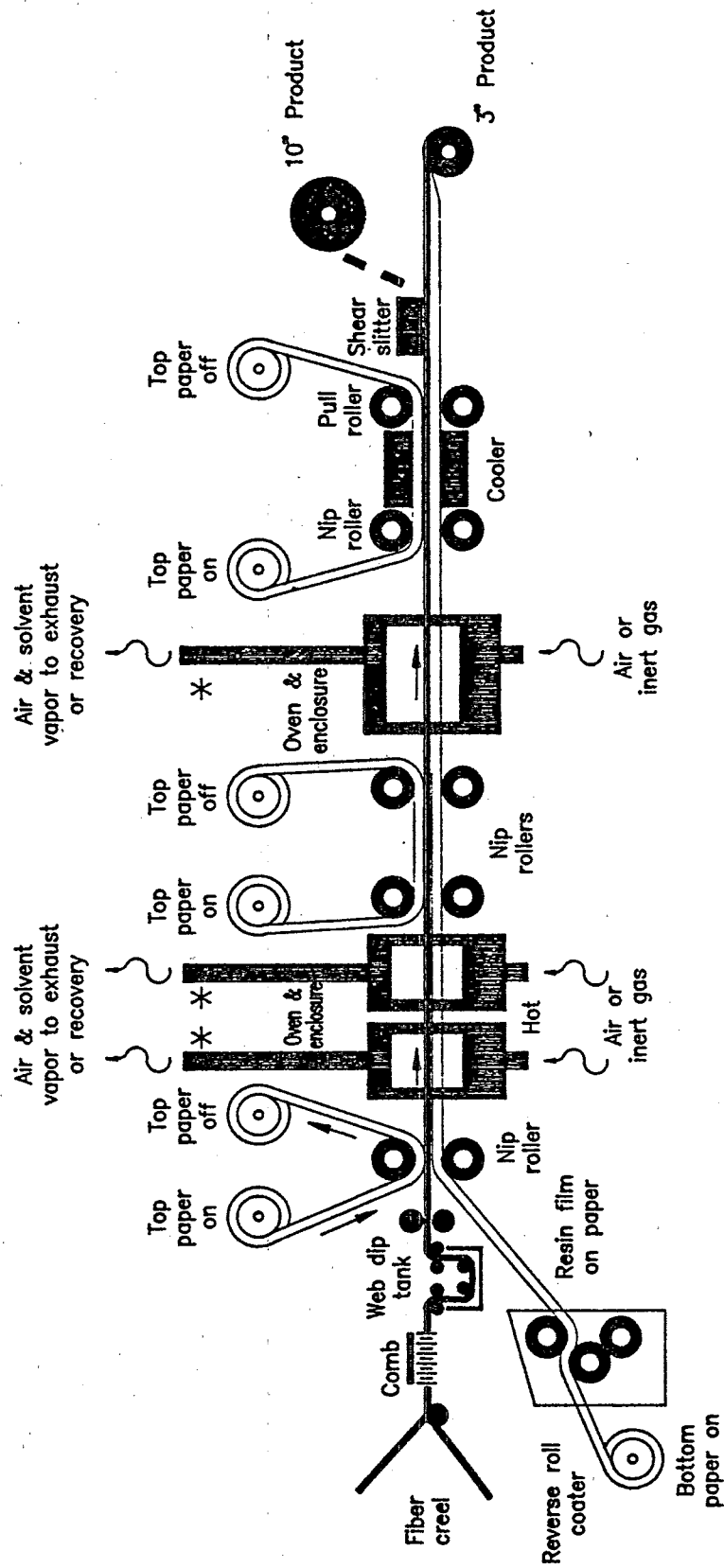


Figure 1. Solution prepegging system.

* Gas Sampling Locations

The primary advantage of solution prepregging over other prepregging options is the high performance levels that are possible with the product. Solution prepreg materials can be designed for extreme environmental conditions, including applications in intense heat and for operations requiring severe strain and puncture resistance. Solution prepregging appears to be the only widely used prepregging process capable of producing the best product performance.

While the product performance of solution-based prepreg material is high, the process of solution prepregging has significant drawbacks. The most obvious of these is that the process requires the use of increasingly regulated organic solvents. The solvent acts as the carrier for the plastic resins which are coated onto the carbon tow. Once the plastic resin is coated, the solvent must be evaporated, usually by means of a drying oven. The vaporized solvent is then either recaptured, incinerated, or otherwise disposed of. Simply venting the solvent to the atmosphere requires permits that are increasingly expensive.

The low solubility of polymer materials in volatile solutions increases the amount of organic solvent used and its subsequent vaporization. Polymer materials used in solution-based prepregging are generally not very soluble. In order to achieve proper coating thicknesses of plastic resins on the carbon tows, large amounts of solution must be used, resulting in the potential for large emissions of VOC.

Another significant problem with solution-based prepregging is that a large solid waste stream of waxed papers is created. After the plastic resin coating is applied, the coated prepreg material is very tacky and will adhere to solution prepregging equipment, thereby fouling the system. To avoid this problem, all rollers handling the prepreg are coated with waxed paper, as shown in Figure 1. This waxed paper is cycled once through the system and is then discarded to avoid fouling the rollers with dirty paper. The paper must be disposed of according to local regulations; in some areas, this material may be considered a hazardous waste.

A third significant problem with solution prepregging is deterioration of the prepreg product after coating. Prepreg materials are not generally manufactured into a usable product immediately after formation but, rather, are stored until needed. During generation of the prepreg, it is not feasible to

evaporate all the solvent in the ovens, as this would leave the prepreg too brittle to be formed into useful shapes. A small amount of solvent must remain in the carbon and plastic matrix to keep it pliable, enabling the solution prepreg to be easily be formed into useful materials. Residual solvent is retained in the prepreg material by keeping it refrigerated and enclosed. Residual solvent will vaporize if the prepreg is left in an open atmosphere, leaving the prepreg material unusable. Refrigeration adds markedly to the cost of producing a solution-based prepreg product. Additionally, residual solvent remaining in the prepreg material may escape directly to the atmosphere during the forming process if control devices are not installed on the forming equipment.

A final drawback is that the process is very slow. A single production line produces only a few meters of tow per minute. Generally, a number of process lines operate in parallel in order to produce large amounts of the material within an acceptable period of time.

1.2.3 The Need for an Alternative

Although solution-based prepregging produces very high quality composite products, it has several disadvantages, especially from an environmental standpoint. Hot melt prepregging is environmentally advantageous and is a relatively simple process, but produces a low quality product.

An alternative prepregging process has been developed by NASA-LaRC which may enable the production of high quality prepreg product in an environmentally acceptable fashion. This process, called dry powder towpregging, employs a finely ground plastic resin which is coated and cured onto a fiber tow material. A test site was established by NASA -LaRC in order to develop the dry powder towpregging process. The ddry powder towpregging line at LaRC is capable of producing over 12 meters (m) of coated tow per minute. Processes and issues relating to the dry powder process are fully discussed in Section 1.3.

1.3 DRY-POWDER PREPREGGING

1.3.1 Description of the Dry-Powder Prepregging Process

Dry powder towpregging, shown in Figure 2, is a conceptually simple process. A finely ground plastic resin is placed into screw-type feeder units. Fiber tow is spread into a thin wall of individual fibers by a fan blower. The ground resin is then deposited onto the spread fibers. The fibers are moved by a series of horizontal rollers, which help to spread the resin across the tow, and are then passed through a curing oven which enjoins the fiber with the ground resin. After exiting the oven, the tow is flipped by a vertical roller so that the underside can be coated. A second feeder coats the bottom of the tow with ground resin, after which it undergoes a second heating cycle in the oven. The fully coated tow is then rolled onto a takeup spool until needed for manufacture of a laminate.

The dry powder towpregging process is environmentally advantageous to solution prepregging in a number of ways. Unlike solution prepregging, dry powder towpregging does not require the use of either solvents or waxed paper, thereby avoiding the associated VOC emissions and solid waste generation. In addition, the towpreg material produced by the NASA Langley process can be stored at room temperature, eliminating additional monetary and environmental costs associated with refrigeration. Environmental impacts associated with prepregging processes are described in Section 3 of this report.

The dry powder towpregging process is similar to the hot melt method of coating prepreg in many ways. Both are relatively simple processes that employ heat to cure plastic resin onto a fiber tow substrate. As stated previously, coating and performance drawbacks seriously limit the use of the hot melt method of prepreg production. These drawbacks occur because hot melt prepregging cannot achieve a smooth and even coating of plastic resin on the fiber tow.

The dry powder towpregging process appears to have potential to overcome the performance limitations of hot melt prepregging. Since dry powder towpregging employs finely ground particles of plastic resin, it could possibly achieve very smooth and even coatings. Coating thicknesses are easily controlled by changing the rate of resin particle deposition onto the surfaces of the fiber tow. Performance levels achieved by the NASA-LaRC process are not discussed in this report. As of this

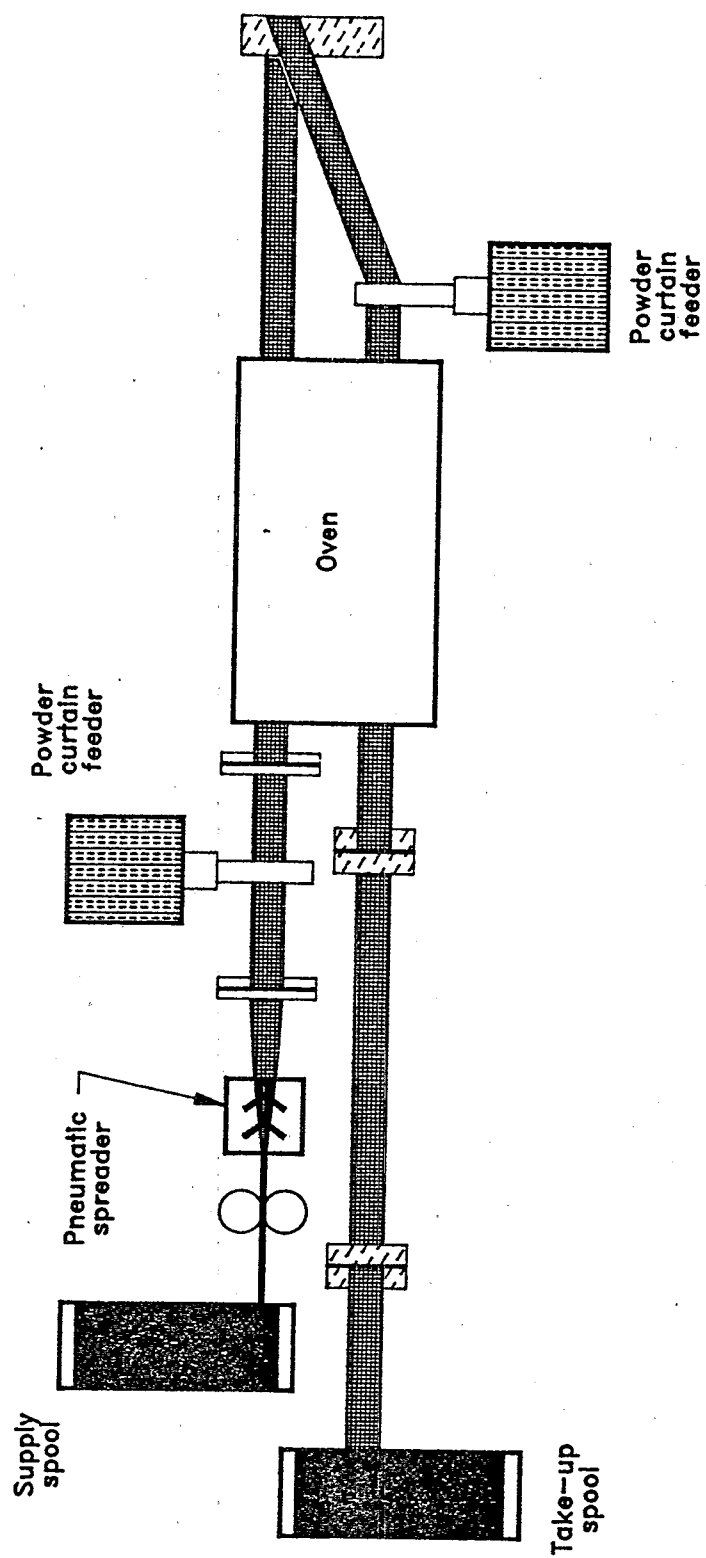


Figure 2. NASA Langley dry powder towpregging system.

NASA-LaRC continues to develop and demonstrate the dry powder towpregging process in order to achieve performance levels comparable to solution prepregging.

1.3.2 Objectives of the Study

The focus of this study is the NASA-LaRC dry powder towpregging process as a potential substitute to a conventional solution prepregging process by describing how similar prepreg material would be produced by each process from the same starting materials. For assessment purposes, this comparison was facilitated by the existence of both the bench scale dry powder towpregging line built by NASA and a similar scaled solution prepregging line, each located in the Polymeric Materials Lab at NASA-LaRC. Main objectives of the study included:

- Assessment of the pollution prevention potential of the process.
- Technical and Economic feasibility of the dry powder process compared to solution prepregging.

Section 2 discusses the method of the study. Potential environmental impacts are discussed in Section 3. An economic assessment is provided in Section 4. Conclusions and recommendations for the NASA-LaRC dry powder towpregging process are presented in Section 5.

SECTION 2

ASSESSMENT METHOD

2.1 DESCRIPTION

2.1.1 Project Parameters

The extent of this project was defined in conjunction with EPA and NASA. Included within the project parameters are all elements of the process cycle for production, from purchase of prepared thermoplastic resins and fiber tow for both processes, through construction of a laminated composite. For comparison purposes, identical raw materials were studied in both processes. Both processes are designed to produce the same product. The study did not include resin or fiber production processes or the ultimate disposal of the laminate in a landfill. These stages were excluded because both processes start with the same resins and fiber tow materials.

2.1.2 Materials

The baseline assumption for the study is that the prepreg produced from both wet solution and dry powder processes would use identical carbon fiber tows possessing identical tow counts. NASA-LaRC provided information on the plastic resins selected for the testing: AMD-0036, a high performance epoxy produced by the 3M Company, and LARC-IA, a resin produced by Imiter Incorporated. Material Safety Data Sheets (MSDS) are presented in Appendix A. NASA-LaRC purchases these resins as powders with a nominal 20 micron particle size. For solvent selection, it was assumed that in solution prepregging, AMD-0036 would be dissolved in methyl ethyl ketone (MEK) and the LARC-IA would be dissolved in n-methyl pyrrolidone (NMP). Hercules Fiber AS-4 12K, which contains 12,000 fibers per tow, was selected as the base tow for each resin product.

2.1.3 Processing Parameters

Figures 1 and 2 display the wet solution and dry powder prepregging processing systems. Process data from the wet solution process system were provided for the following parameters:

- tow speed
- solution temperature
- solution consumption
- curing oven temperature
- curing oven energy input
- release paper consumption

For the dry towprepping process, process data were provided for the following parameters:

- tow speed
- curing oven temperature
- curing oven energy input
- powder feed rate
- feeder power consumption

Organic vapors from the solution prepregging process and from the fiber sizing operation would constitute the primary environmental impacts from this process. The use of fine, dry powders creates the potential for fugitive dust emissions. Expanded development of dry powder towprepping systems to the operational level may entail a requirement for subsequent particulate control equipment.

Energy consumption is an important consideration because process operating costs generally determine the acceptance of a process by industry. Further, energy generating operations have environmental impacts raising concerns for conservation. Therefore, power consumption of components in both process systems was included in the study. Energy consumption, along with the treatment costs for organic and solid wastes, comprise the major factors in process operating costs. Energy costs for

refrigeration of wet-solution produced prepreg are not included in this study because these costs are highly variable, depending on the length and conditions of storage time. Also, organic and solid waste treatment costs were not estimated due to the existence of variables in production rate, scale of operations and to maintain conservative numbers for the economic assessment.

2.1.4 Waste Reduction Potential

Potential reductions in solvent use and emissions to the environment are projected for the NASA-LaRC process. Information gathered during this study has been utilized to project the waste reduction potential of the dry powder process. The reduction in solvents was balanced against projected emissions of fine particulate thermoplastic resin from the process. Based on process performance experience at NASA-LaRC, information is provided on projected VOC emissions from solution prepregging and sizing operations, energy consumption in the solution prepregging curing ovens, and estimates of fugitive dust emissions from the dry powder feeders or web prior to curing, particulate emissions from the dry powder towprepping chamber, and organic vapors from the dry powder towprepping curing oven.

2.1.5 Economic Assessment

System capital and operating costs have been estimated as part of an overall life cycle cost assessment of the prepregging processes. The boundaries of the cost assessment are the starting raw materials (*i.e.*, fiber tow, polymer, and support materials such as release paper, if used) through the fabricated parts. Initial preparation of the raw materials and the ultimate disposal of the discarded parts are outside the boundaries of the economic assessment, because they are assumed not to be significantly different.

2.2 PROCESS ASSESSMENT

2.2.1 Typical Operating Conditions

As noted in section 2.1.2, this study compares both processes on the basis of both a thermoplastic and an epoxy product. The epoxy was AMD-0036, and the thermoplastic was LARC-IA. AMD-0036 was assumed to be dissolved in MEK for solution prepregging, with the LaRC-IA dissolved in

NMP. In the dry powder process no solvents are used. For operating conditions information, the study set its parameters to the size and scale of equipment typically used in NASA-LaRC labs, as that information was readily available. The average operating conditions of this equipment are shown in Table 1.

TABLE 1. OPERATING CONDITIONS

Run No.	Polymer Type & Process	Tow Speed ft/min	Total Tow, ft	Oven Temp. °C	Paper usage, ft ²	Power Consumption, Kw
1	LARC-IA, Dry	70.0	8050	300°C	0	5
2	AMD-0036, Dry	40.0	5080	190°C	0	5
3	LARC-IA/NMP, 30% solids*	2.0	3375	71°C	880	27
4	AMD-0036/MEK, 70% solids*	1.3	2535	205 C	670	27

*Solution processing

2.2.2 Additional Parameters

A number of other parameters were included for this study, as described in Section 2.1.3. Curing oven temperature was provided by NASA-LaRC, along with average tow speed and total tow length. Curing oven energy input was based on nameplate power requirements indicated on the ovens used for both systems. Air flow rates into the curing ovens were also available on the equipment nameplates.

Release paper consumption during each of the wet solution processes is provided by weight. Feeder power consumption was available on the equipment nameplates during the dry towpregging process. Powder feed rates were provided by NASA-LaRC.

SECTION 3

ENVIRONMENTAL ASSESSMENT

The first objective of this study was to calculate the potential environmental impacts of both processes, in the areas of VOCs, solid waste and particulate emissions. Table 2 provides the estimated waste reduction potential in these categories.

TABLE 2. ESTIMATED WASTE REDUCTION POTENTIAL OF THE NASA-LaRC PROCESS*

Process	VOC Emissions lb/yr	Solid Waste lb/yr	Particulate Emissions lb/yr
Polyamide - Dry Process	0	0	1
Epoxy - Dry Process	0	0	7
Polyamide - Solution in NMP	>1	866,160**	>1
Epoxy - Solution in MEK	15,230	866,160**	>1

*These estimates are generated assuming annual production rates equivalent to those shown in Table 1, accounting for 2000 hours operating time per year.

**This is the weight of the paper waste generated by the solution-based process assuming an annual production of 48,000 linear meters of 89 mm wide prepreg. Paper waste is generated at the rate of approximately 167.4 kg per 1000 linear meters of tape produced. Other wastes, such as drums for solvents and resin containers and accumulated particulate matter generated by the dry powder process, were not calculated.

3.1 SOLVENTS AND PARTICULATES

As the table shows, VOCs would be eliminated by the dry powder prepregging, because no VOC generating materials are used in the process. The reduction of VOC emissions for the epoxy would be much greater than the thermoplastic, which reflects the fact that MEK is significantly more volatile than NMP. With MEK as a common solvent in many prepregging operations, this level of reduction can generate significant cost savings in terms of environmental control equipment and maintenance.

A significant emission source in conventional prepregging operations is the residual solvent that might be released as the prepreg is used to produce composite materials. In the dry towpreg material, the only residual solvents present are those resulting from the resin production, as no additional solvents

are used in the towpreg production. The solution process, on the other hand, may generate material that contains significant residual solvent. Although emissions from the wet solution prepreg material during product formation have not been quantified during this evaluation, these emissions are potentially significant.

3.2 SOLID WASTE

The wet solution prepregging process produces solid waste in the form of waxed paper, which is used to prevent prepreg from touching the rollers of the prepregging equipment. The paper rolls through the equipment along with the fiber tow, as shown in Figure 1. This paper cannot be reused because it is contaminated with tow and resin, and must be disposed of after one pass through the prepreg line. The amount of waste paper generated is variable, depending on the tow speed as presented in Table 1. For an annual production rate, using the LARC-IA polymer in NMP solvent, approximately 3,375 feet of tow per year will be produced, generating 866,160 pounds of waste paper annually.

The NASA dry powder towpregging process produces essentially no solid waste. Waxed paper use is not required for equipment protection, and no products other than fiber tow, plastic resin, and energy are consumed in the process. An additional solid waste stream may be produced by the accumulated particulates generated by the dry powder process and removed by particulate control equipment. This material will primarily consist of fine particles of plastic polymer, and will require disposal or recycling.

3.3 SUMMARY OF ENVIRONMENTAL ISSUES

The primary focus of this study was to ascertain the estimated reduction of VOC emissions from prepregging operations, the first step in the production of polymer composites. The NASA Langley dry powder towpregging process has the potential to significantly reduce or eliminate VOC emissions from the prepregging operation.

As shown in Table 2, VOC emissions are virtually eliminated in the dry powder towpregging process. When MEK is the solvent, as is the case in many prepregging operations, reductions of this magnitude can result in significant savings in terms of avoided costs for environmental process controls.

Even when less volatile solvents such as NMP are utilized, the elimination of VOC emissions is desirable. Also, the elimination of liquid hazardous waste is a benefit.

Solid wastes are significantly reduced by eliminating the use of release paper in the dry powder process. In a typical wet solution prepregging system, release paper contributes 167.4 kg of solid waste for every 1,000 meters of tow processed. These solid wastes are potentially contaminated with the organic solvents used in the process and could therefore be subject to disposal restrictions.

Although some particulate emissions are produced by the dry powder towpregging process line currently operating at NASA Langley, conventional particulate control technology would significantly reduce these emissions. Accumulated particulates removed by control equipment would eventually represent an additional solid waste stream consisting primarily of polymer material, which would require disposal or recycling. Particulates are not emitted from the solution process.

SECTION 4 ECONOMIC ISSUES

4.1 EQUIPMENT AND PRODUCTION COST EVALUATION

A preliminary economic evaluation of the dry powder towpregging process was performed using general chemical engineering cost estimating procedures. The economic evaluation focuses on the wet solution and dry powder epoxy systems, since this demonstration was primarily interested in eliminating the use of organic solvents (MEK). VOC emissions from the solution process using NMP would be small. The following assumptions were made for the economic analysis:

- (1) The dry process operates at 21.3 m/min and produces 2,556,000 linear meters of 89 mm tape annually.
- (2) The solution process operates at 0.61 m/min and produces 73,200 linear meters of 89 mm tape annually.
- (3) The dry process can be scaled up to coat 15 tows simultaneously.
- (4) The dry process can be made to produce a 89 mm tape using hot nip rolls.
- (5) The dry process has an epoxy powder loss of approximately 15 percent, due to recycling and handling.
- (6) No epoxy powder losses are experienced with the wet solution process.
- (7) Power usage is estimated from equipment name plate data.
- (8) No costs were included in either process for such items as:
 - (a) supervision
 - (b) maintenance
 - (c) laboratory charges
 - (d) taxes
 - (e) insurance
 - (f) plant overhead
 - (g) administrative costs
 - (h) distribution and selling costs

- (i) research and development
- (j) financing
- (k) emissions control equipment
- (l) waste disposal
- (m) refrigeration

- (9) The dry process was assumed to have a three year lifetime expectancy, and the solution process a five year lifetime expectancy, both with no scrap value. Linear depreciation was used in each case.

4.1.1 Capital Costs

The major items of equipment involved in the dry powder towpregging process have been estimated from manufacturers' quotations, NASA Langley information, and Peters and Timerhaus scale-up factors. Since the bench scale process at NASA Langley is the only known process of this type, the capital cost estimates are based on the bench scale process scaled up by a factor of five. The scaled-up equipment would produce an amount equivalent to that produced by the 15-tow wet solution prepregging process in use at NASA Langley. The wet solution prepregging process (15 tows) at NASA produces a 89 mm wide tape. In the capital cost estimate for the dry process, an attempt was made to include the equipment required to also produce a 89 mm tape. The preliminary estimate is, at best, within an accuracy of 50 percent.

Estimated capital costs for the dry powder towpregging process are shown in Table 6. The total capital cost is estimated at \$402,700. Reported capital costs for the wet solution prepreg process equipment at NASA Langley are \$650,000. If we assume 50 percent accuracy of the dry powder process capital cost estimate, the total dry powder towpregging capital costs are comparable to, and possibly less than, the reported capital costs for the wet solution prepreg process at NASA. Because of the different line speeds (*i.e.*, 21.3 m/min versus 0.61 m/min), the dry process will produce approximately 35 times more product than the wet solution process annually. Annual operating costs for the wet solution process are less than those of the dry powder process. However, this difference is more than compensated for by the difference in production rates. Because the dry process has a much higher line speed than the solution process (see Table 1), there are cost savings to be gained in the higher annual production rate by the dry powder process. The estimated cost of producing a 89 mm tape by the solution process is \$5.38 per meter while the dry process is estimated at only about \$0.94 per meter.

4.1.2 Operating Costs

Operating costs have been estimated, on an annual and per-unit-production basis, for both the dry powder towpreg process and the wet solution prepregging process at NASA Langley. Operating costs for the dry powder process have been adjusted to reflect the production of an equivalent of 15 tows simultaneously, at 89 mm. Estimated operating costs for both processes are shown in Table 4.

4.2 SUMMARY

This economic analysis has demonstrated that epoxy-coated prepreg can be produced by the dry powder process for approximately 18 percent of the costs associated with the wet solution process (\$0.94 per meter, versus \$5.38 per meter). Such a cost reduction should easily offset any development costs necessary to provide an acceptable product from the dry powder process. Capital costs for the dry powder and wet solution process lines are estimated at \$402,700 and \$650,000, respectively. These costs are comparable, within the 50 percent margin of error associated with their estimation.

A large number of assumptions were made for this economic comparison, as shown in Section 4.1. A principal assumption is that the dry process can be scaled up to simultaneously produce 15 tows, resulting in a 89 mm wide tape similar to that produced by the wet solution process. Additional assumptions include the omission of several costs, including emissions control equipment and refrigeration costs. Refrigeration of the solution process prepreg will be necessary to maintain its value. No such refrigeration is necessary with the dry powder towpreg material. Refrigeration costs were not included but would increase the operating cost of the solution process, perhaps significantly. Emissions control equipment is another item which may differentially affect the two processes, since the wet solution process would require controls for VOC emissions while the dry powder process would require particulate emissions controls. Due to the large number of simplifying assumptions made in the economic analysis, cost estimates for both processes should be considered as comparative costs only and not as detailed capital and operating cost estimates.

TABLE 3. DRY TOWPREG CAPITAL COST ESTIMATE

Estimated Major Equipment Costs	
Equipment	Estimated Cost, K \$
Fiber Feed Spool Creel and Tension Brake (1)	40.0
Pneumatic Spreaders (2)	12.0
Powder Feeders (2)	30.0
Vibrators (4)	1.2
Electrical Variacs (4)	1.2
Electric Oven (1)	13.5
Powder Overfeed Collection and Recycle (2)	10.0
Hot Nip Rollers (2 sets)	60.0
Rollers (8)	8.0
Take up Spools and Speed Control (1)	60.0
Exhaust Ventilation Blower (2)	18.0
Total Estimated Major Equipment Cost	253.9
Estimated Direct Costs	
	Estimated Cost, K \$
Major Equipment	253.9
Installation (10% of equipment cost)	25.4
Instrumentation and Controls (5% of equipment cost)	12.7
Piping (2% of equipment cost)	5.1
Electrical (5% of equipment cost)	12.7
Total Estimated Direct Costs	309.8
Indirect Costs (@ 30% of direct costs)	92.9
Total Estimated Capital Cost	402.7

TABLE 4. PRODUCTION COST ESTIMATE

Dry Powder Process		Est. Cost, K \$
<hr/>		
Raw Materials*		
Fiber, AS-4 (12 K) (\$55/kg, = 1176 m)		1,800.0
Epoxy Powder (3M, AMD-0036) (\$209/kg)		380.0
Labor		
1 operator (\$20/hr x 2000 hr)		40.0
1 helper (\$14/hr x 2000 hr)		28.0
Utilities (40,000 Kwh/yr @ \$0.10/Kwh)		4.0
Rent (1500 ft ² @ \$12/ft ² /yr)		18.0
Depreciation (3 yr life @ \$402,700)		134.0
Total Annual Cost		\$2,404.0
@ 2,556,000 m/yr of 89 mm tape		\$0.94/m
<hr/>		
Wet Solution Process with MEK		Est. Cost, K \$
<hr/>		
Raw Materials		
Fiber, AS-4 (12 K) (\$55/kg = 1176 m)		51.4
Epoxy powder (3 M, AMD 0036) (\$209/kg)		78.2
MEK (\$2.56/liter = 0.82 kg)		0.8
Paper		36.0
Labor		
1 operator (\$20/hr x 2000 hr)		40.0
1 helper (\$14/hr x 2000 hr)		28.0
Utilities (60,000 Kwh/yr @ \$0.10/Kwh)		6.0
Rent (2,000 ft ² @ \$12/ft ² /yr)		24.0
Depreciation (5 yr life @ \$650,000)		130.0
Total Annual Cost		\$394.4
@ 73,200 m/yr of 89 mm tape		\$5.38/m

***Fiber Cost**

(1) Dry Powder Process				
\$55.00	x	2,556,000 m	x	15 process lines = \$1,800 K
1,175.6 m		yr		
(2) Wet Solution Process				
\$55.00	x	73,200 m x	15 process lines = \$51.4 K	
1,175.6 m		yr		

Epoxy and solvent costs are based on usage rates experienced during the evaluation, for Run numbers 2 and 4. Usage rates for the dry process have been scaled up by a factor of 5, to account for the production of an equivalent of 15 tons at 89 mm.

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

The NASA-LaRC dry powder towpregging process shows considerable promise as an alternative prepregging process for production of polymer composites, suggesting the potential to achieve significant reductions in VOC emissions and solid wastes when compared to conventional technology, while greatly reducing production costs.

In order for the NASA LaRC dry powder towpregging process to become widely accepted by industry, the physical properties of the material produced must be comparable to those of the material it is replacing. Measurements of the strength of the coated fibers and the impact resistance of dry towpreg materials must be evaluated in comparison to solution prepreg. After adequate testing is performed, the process may prove acceptable, or may require the development of alternative lamination procedures to improve performance levels.

Even if performance levels are shown to require improvement, the development costs of an improved process would likely be more than offset by the reduction in environmental impacts and processing costs achieved by the dry powder towpregging process.

APPENDIX A
MATERIAL SAFETY DATA SHEETS

Product Data

NUMBER 847-6
(Supersedes 847-5)

HERCULES® CARBON FIBER Type AS4

HERCULES® Type AS4 carbon fiber is a continuous, high-strength, high-strain, PAN-based fiber available in 3,000 (3K)-, 6,000 (6K)- and 12,000 (12K)-filament-count tows. The fiber has been surface-treated and sized to improve its interlaminar shear properties, handling characteristics, and structural properties, and is suggested for use in weaving, prepregging, filament winding, pultrusion, and molding compounds. Sizes compatible with various resin systems are available to improve handling characteristics and structural properties.

Typical Fiber Properties	U.S. Units	SI Units
Tensile strength ^(a)	570,000 psi	3,930 MPa
Tensile modulus ^(a)		
Tangent at 1/2 load	36 x 10 ⁶ psi	248 GPa
Chord 5000-1000	32 x 10 ⁶ psi	221 GPa
Ultimate elongation ^(a)	1.60%	1.60%
Carbon content	94.0%	94.0%
Density	0.065 lb/in ³	1.79 g/cm ³
Specific heat		
at 167°F (75°C)	0.22 Btu/lb, °F	0.22 cal/g, °C
at 347°F (175°C)	0.27 Btu/lb, °F	0.27 cal/g, °C
Electrical resistance, 12K	9.6 ohms/ft	0.32 ohm/cm
Electrical resistivity, 12 K	5.03 x 10 ⁻³ ohm-ft	1.53 x 10 ⁻³ ohm-cm

Typical Epoxy Composite Properties (at Room Temperature)		
Tensile strength	310,000 psi	2,139 MPa
Tensile modulus	20.5 x 10 ⁶ psi	141 GPa
Flexural strength	250,000 psi	1,724 MPa
Flexural modulus	18.5 x 10 ⁶ psi	128 GPa
Short-beam shear strength	18,500 psi	128 MPa
Fiber volume	62%	62%

^(a) Calculated from tow test data.

(over)

We cannot anticipate all conditions under which this information and our products, or the products of other manufacturers in combination with our products, may be used. We accept no responsibility for results obtained by the application of this information or the safety and suitability of our products, either alone or in combination with other products. Users are advised to make their own tests to determine the safety and suitability of each such product or product combination for their own purposes. Unless otherwise agreed in writing, we sell the products without warranty, and buyers and users assume all responsibility and liability for loss or damage arising from the handling and use of our products, whether used alone or in combination with other products.

HW-1000752 (2/81)

Yarn/Tow Characteristics	U.S. Units	SI Units
Filament diameter	0.315 mil	8 microns
Filament shape	Round	Round
Twist	None	None
Tow cross-sectional area		
3K	$1.82 \times 10^{-4} \text{ in}^2$	0.12 mm ²
6K	$3.67 \times 10^{-4} \text{ in}^2$	0.24 mm ²
12K	$7.54 \times 10^{-4} \text{ in}^2$	0.48 mm ²
Approximate yield		
3K	7,060 ft/lb	4.74 m/g
6K	3,500 ft/lb	2.35 m/g
12K	1,700 ft/lb	1.17 m/g
Weight/length		
3K	$11.8 \times 10^{-6} \text{ lb/in}$	0.211 g/m
6K	$23.8 \times 10^{-6} \text{ lb/in}$	0.425 g/m
12K	$48.0 \times 10^{-6} \text{ lb/in}$	0.857 g/m

Available Sizing

Epoxy-compatible sizes for prepregging, filament winding, braiding, and weaving are available on request.

Other resin-compatible sizes are also available to satisfy customer needs.

Packaging

A standard package of 12K fiber contains 4 lb; 3K fiber and 6K fiber packages contain 2 to 3 lb; other package sizes are available on request. The fiber is wound on a 3-in.-ID by 11-in.-long cardboard cylinder and overwrapped with plastic film.

Safety Information

Obtain, read, and understand the Material Safety Data Sheet (MSDS) before use of this product.

**For Further Information,
Please Contact:**

Hercules Advanced Materials
and Systems Company
Composite Products Group
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Magna, UT 84044-0098
Tel: (801) 251-5372
(800) 443-4237
Fax: (801) 251-3268

Hercules Japan Ltd. (HJL)
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Hercules France S.A.
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France

Tel: 33-1-47-51-2919
Fax: 33-1-47-08-5075

MATERIAL SAFETY DATA SHEET

MANUFACTURER'S NAME: IMITEC, INC.
1990 Maxon Rd - PO Box 1412
Schenectady, NY 12301

DATE OF PREPARATION: Feb. 7, 1992
Updated 5/18/92

EMERGENCY PHONE NO.: 1-518-374-9101
INFORMATION PHONE NO.: 1-518-374-9101

SECTION I - PRODUCT IDENTIFICATION

PRODUCT NUMBER: X-881
PRODUCT NAME: LARC-IA
PRODUCT CLASS: Polyimide Adhesive

SECTION II - HAZARDOUS INGREDIENTS

INGREDIENT	PERCENT	OCCUPATIONAL EXPOSURE LIMITS		VAPOR PRESSURE
		TLV	PEL	
1-Methyl-2-Pyrrolidinone (NMP)	70.0	NA	NA	.29 mm Hg at 20 deg. C
Polyamic acid	30.0	NA	NA	NA
$C_8H_8O_3 - (C_{10}H_{10}O_2N_2)_n - C_8H_8O_3$				

*As recommended by supplier.

SECTION III - PHYSICAL DATA

BOILING RANGE: 202 deg. C
EVAPORATION RATE: Slower Than Ethyl
WT/GAL: 9.17#/Gal.

VAPOR DENSITY: Heavier Than Air
70% VOLATILE VOLUME

SECTION IV - FIRE AND EXPLOSION HAZARD DATA

FLAMMABILITY CLASSIFICATION:

OSHA: IIIA
LEL: NA

FLASH POINT: 187 deg. F
DOT: Combustible Liquid

EXTINGUISHING MEDIA:
FOAM

"ALCOHOL" FOAM

CO₂

DRY CHEMICAL

UNUSUAL FIRE AND EXPLOSION HAZARDS: NA

SPECIAL FIREFIGHTING PROCEDURES: Firefighters should be equipped with self-contained breathing apparatus and turn-out gear.

SECTION V - HEALTH HAZARD DATA

EFFECTS OF OVEREXPOSURE: Skin and eye irritation. Vapor inhalation may cause headache, nausea, impairment of coordination and reaction time.

MEDICAL CONDITIONS PRONE TO AGGRAVATION BY EXPOSURE: NA

PRIMARY ROUTE(S) OF ENTRY: DERMAL INHALATION

EMERGENCY AND FIRST AID PROCEDURES: Inhalation - move to fresh air to improve breathing. Remove contaminated clothing. Eye contact - flush with water for at least 15 minutes. Call physician.

SECTION VI - REACTIVITY DATA

STABILITY: STABLE

HAZARDOUS POLYMERIZATION: WILL NOT OCCUR

HAZARDOUS DECOMPOSITION PRODUCTS: CO and NO_x fumes emitted when heated to decomposition.

CONDITIONS TO AVOID: NA

INCOMPATIBILITY (MATERIALS TO AVOID): Strong oxidizing agents.

SECTION VII - SPILL OR LEAK PROCEDURES

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED:
Avoid prolonged contact with skin and breathing vapor.
Remove sources of ignition.
Remove with inert absorbent.

WASTE DISPOSAL: Disposal method must comply with local, state and federal regulation.

SECTION VIII - SAFE HANDLING AND USE INFORMATION

RESPIRATORY PROTECTION: Use NIOSH/MSHA respirator TC-23C.

VENTILATION: Provide sufficient ventilation to keep below TLV/LEV.

PROTECTIVE GLOVES: Use when prolonged or repeated contact.

EYE PROTECTION: Use safety eyewear.

OTHER PROTECTIVE EQUIPMENT: NA

HYGENIC PRACTICES: Wash thoroughly after handling.

SECTION IX - SPECIAL PRECAUTIONS

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORING: Keep away from heat, sparks and open flame. Close container after each use. Do not store above 100 deg. F.

OTHER PRECAUTIONS: Wash thoroughly after handling and before eating and smoking. Observe label precautions. Containers should be grounded when pouring.

The information contained herein is provided in good faith and is believed to be correct.

3M General Offices
3M Center
St. Paul, Minnesota 55144-1000
612/733-1110
Duns No.: 00-617-3082

00-02
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MATERIAL SAFETY
DATA SHEET

3M

DIVISION: AEROSPACE MATERIALS DEPARTMENT
MATERIAL:

3M EXPERIMENTAL EPOXY POWDER AMD 0036

3M I.D. NUMBER: 63-0000-0096-6

ISSUED: JULY 6, 1992

SUPERSEDES: JULY 2, 1992

DOCUMENT: 05-5363-6

1. INGREDIENT	C.A.S. NO.	PERCENT
AMINE CURATIVE - TRADE SECRET (T.S.)..	TradeSecret	30.0 - 60.0
AROMATIC DIGLYCIDYL ETHER - TRADE SECRET (T.S.)	TradeSecret	15.0 - 40.0
EPOXY RESIN	29690-82-2	15.0 - 40.0
EPOXY RESIN	25036-25-3	15.0 - 40.0

2. PHYSICAL DATA

BOILING POINT:..... N/A
VAPOR PRESSURE:..... N/A
VAPOR DENSITY:..... N/A
EVAPORATION RATE:..... N/A
SOLUBILITY IN WATER:..... Insoluble
SP. GRAVITY:..... 1.200 Water = 1
PERCENT VOLATILE:..... 0.00 % by wt
VOLATILE ORGANICS:..... N/D
VOC LESS H2O & EXEMPT SOLVENT N/D
pH:..... N/A
VISCOSITY:..... N/A
MELTING POINT..... N/D
APPEARANCE AND ODOR: powder, light purple to tan, slight odor

3. FIRE AND EXPLOSION HAZARD DATA

FLASH POINT:..... N/A
FLAMMABLE LIMITS - LEL:..... N/A
FLAMMABLE LIMITS - UEL:..... N/A
AUTOIGNITION TEMPERATURE: ... N/D
EXTINGUISHING MEDIA:
CO2, foam, dry chemical, water
SPECIAL FIRE FIGHTING PROCEDURES:
Fire fighters should be equipped with self-contained breathing apparatus when fighting fires involving this product.
UNUSUAL FIRE AND EXPLOSION HAZARDS:
None
NFPA-HAZARD-CODES: HEALTH 1 FIRE 0 REACTIVITY 1
UNUSUAL REACTION HAZARD: none

4. REACTIVITY DATA

STABILITY: Stable
INCOMPATIBILITY - MATERIALS TO AVOID:
N/A CONDITIONS TO AVOID: Storage at 0F or lower is required to maintain product shelf life. Allow resin to warm to room temperature.

Abbreviations: N/D - Not Determined N/A - Not Applicable

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**MATERIAL SAFETY
DATA SHEET**

3M

**MSDS: 3M EXPERIMENTAL EPOXY POWDER AMD 0036
JULY 6, 1992**

PAGE: 2 of 4

4. REACTIVITY DATA (continued)

HAZARDOUS POLYMERIZATION: Will Not Occur
HAZARDOUS DECOMPOSITION PRODUCTS:
CO and CO₂ when subjected to excessive heat or flame.

5. ENVIRONMENTAL INFORMATION

SPILL RESPONSE:

Ventilate the area. Observe precautions from other sections, particularly Section 7. Collect spilled material. Place collected material in a Department of Transportation approved metal container lined with a polybag and seal.

RECOMMENDED DISPOSAL:

Incinerate bulk product after mixing with flammable material in an industrial or commercial facility. Disposal should be in accordance with applicable regulations.

ENVIRONMENTAL DATA:

Volatile Organic Compound (VOC):
Maximum VOC = N/A.
Maximum VOC minus Water minus Exempt Solvents = N/A.

SARA HAZARD CLASS:

FIRE HAZARD: No **PRESSURE:** No **REACTIVITY:** No **ACUTE:** Yes **CHRONIC:** Yes

6. SUGGESTED FIRST AID

EYE CONTACT:

Flush eyes with plenty of water for at least 10 minutes. Call a physician.

SKIN CONTACT:

Thoroughly wash affected area with soap and water.

INHALATION:

Remove person to uncontaminated air. Call a physician.

IF SWALLOWED:

Do not induce vomiting. Immediately call a physician or poison control center.

7. PRECAUTIONARY INFORMATION

OTHER PRECAUTIONARY INFORMATION:

FOR INDUSTRIAL USE ONLY. FOR INVESTIGATIONAL USE ONLY. To protect yourself, you must wear impervious gloves, chemical safety goggles and clothing which covers any exposed areas of the arms, legs and torso while handling this material. Use impervious gloves (e.g., Viton or nitrile rubber) and Tyvek coveralls. Discard contaminated clothing or launder before reuse. Keep container closed when not in

Abbreviations: N/D - Not Determined N/A - Not Applicable

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MATERIAL SAFETY
DATA SHEET

3M

MSDS: 3M EXPERIMENTAL EPOXY POWDER AMD 0036
JULY 6, 1992

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7. PRECAUTIONARY INFORMATION (continued)

use. Use only in areas with proper ventilation to prevent dusting. Avoid breathing vapors released during heat curing. Curing equipment should be properly vented to a suitable emission control system or to the outdoors. Any person who may be exposed to the powder or vapor shall, at a minimum wear a NIOSH approved, category 19C, Type C supplied air respirator, operated in pressure demand or positive pressure mode, and equipped with a full facepiece. Use of the respirator shall be according to 29CFR 1910.13A and 30 CFR 11 Subpart J. Use local exhaust ventilation and appropriate eye, skin and respiratory protection if dusting occurs during cutting and processing of cured specimens.

INGREDIENTS	EXPOSURE LIMITS		VALUE	UNIT	TYPE AUTH	SKIN*
AMINE CURATIVE - TRADE SECRET (T.S.)..			NONE	NONE	NONE	NONE
AROMATIC DIGLYCIDYL ETHER - TRADE SECRET (T.S.)			NONE	NONE	NONE	NONE
EPOXY RESIN			NONE	NONE	NONE	NONE
EPOXY RESIN			NONE	NONE	NONE	NONE

* SKIN NOTATION: Listed substances indicated with "Y" under SKIN refer to the potential contribution to the overall exposure by the cutaneous route including mucous membrane and eye, either by airborne or, more particularly, by direct contact with the substance. Vehicles can alter skin absorption.

SOURCE OF EXPOSURE LIMIT DATA:
- NONE: None Established

8. HEALTH HAZARD DATA

EYE CONTACT:
May cause eye irritation on contact.

SKIN CONTACT:
May cause skin irritation. May cause an allergic skin reaction in some persons.

INHALATION:
Vapors may cause respiratory system irritation.
Symptoms include coughing, sneezing and itching.

IF SWALLOWED:
May be harmful if swallowed. Symptoms of ingestion may include nausea and vomiting.

OTHER HEALTH HAZARD INFORMATION:
Chemicals similar in structure to the amine curative and aromatic diglycidyl ether have been found to cause cancer, retinopathy and liver and reproductive toxicity in laboratory animals.

Abbreviations: N/D - Not Determined N/A - Not Applicable

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3M Center
St. Paul, Minnesota 55144-1000
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Duns No.: 00-617-3082

00-02
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MATERIAL SAFETY
DATA SHEET

3M

MSDS: 3M EXPERIMENTAL EPOXY POWDER AMD 0036
JULY 6, 1992

PAGE: 4 of 4

8. HEALTH HAZARD DATA

(continued)

NOTE: Although the U.S. E.P.A. review of the trade secret amine curative has indicated that this material may cause the health effects that have been delineated above, the toxicity testing that has been performed on this material may help to put the E.P.A. assessment into perspective. SKIN SENSITIVITY STUDY: The amine curative has been shown to cause minimal and no skin irritation in albino rabbits. The amine curative is not considered a skin sensitizer based on the results of a guinea pig maximization test. ACUTE TOXICITY STUDY: The acute dermal toxicity in the rat is greater than 2000 mg/Kg bodyweight and the acute oral toxicity in the rat is greater than 5000 mg/Kg bodyweight. MUTAGENICITY STUDY: The amine curative recorded negative results in the following four mutagenicity assays: Ames (Salmonella typhimurium strains TA 1535, TA 1537, TA 1538, TA 98 and TA 100), yeast (Saccharomyces cerevisiae), human lymphocyte, and mouse lymphoma. ORAL TOXICITY STUDY: In a 28 day oral toxicity study in rats, the amine curative was dosed at 3 levels; 10, 100 and 1000 mg/Kg/day. The 1000 mg/Kg/day dose caused minimal toxicity and the 100 mg/Kg/day dose is considered to be a level at which no adverse signs of toxicity were observed. The effects at 1000 mg/Kg/day included decreased lymphocyte and total white blood cell count in one of five female rats. In addition, an increase in adjusted liver and adrenal weights was observed for female rats dosed at 1000 mg/Kg/day. Histologically, only minimal centrilobular hepatocyte enlargement was observed in one of five females treated at this dose level. No histological changes were noted in the adrenals. Overall, the findings observed at 1000 mg/Kg/day were considered to be of a minor nature by the independent testing facility that conducted the study. MORE INFORMATION: More complete detail of these test results is available on request.

SECTION CHANGE DATES

HEADING

SECTION CHANGED SINCE JULY 2, 1992 ISSUE

Abbreviations: N/D - Not Determined N/A - Not Applicable

The information on this Data Sheet represents our current data and best opinion as to the proper use in handling of this material under normal conditions. Any use of the material which is not in conformance with this Data Sheet or which involves using the material in combination with any other material or any other process is the responsibility of the user.

Fluka

Fluka Chemical Corp.
980 South Second Street
Ronnkonoma, New York 11779

Phone 516-467-0980
Telex 96-7807
Fax 516-467-0663

Technical Dept.

Orig. to J. Derern/R. Elu 52
ATTN: SAFETY DIRECTOR
SUZANNE ZAREMSKI
BIONETICS/SCI & TECH GRP
MAIL STOP 429/JLDG. 1102T
NASA LANGLEY RES CTR
HAMPTON

VA 23665

EMERGENCY PHONE 1-516-467-3535

DATE: 02/06/92
CUST#: 000000
PO#:

M A T E R I A L S A F E T Y D A T A S H E E T P A G E 1

IDENTIFICATION

PRODUCT #: 69120
CAS #: 872-50-4
MF: CSH9ND

NAME: 1-METHYL-2-PYRROLIDONE

SYNONYMS

Non-Hazardous DOT Material
N-METHYLPYRROLIDINONE * N-METHYL-2-PYRROLIDINONE * 1-METHYL-2-PYRROLIDINONE * 1-METHYL-5-PYRROLIDINONE * METHYLPYRROLIDONE * N-METHYLPYRROLIDONE * N-METHYL-ALPHA-PYRROLIDONE * N-METHYL-2-PYRROLIDONE * 1-METHYL-2-PYRROLIDONE * M-PYROL * NMP *

TOXICITY HAZARDS

SPECS NO: UY5790000

2-PYRROLIDINONE, 1-METHYL-

IRRITATION DATA

EYE-RBT 100 MG MUD

TOXICITY DATA

ORL-RAT LD50: 3914 MG/KG
IPR-RAT LD50: 2472 MG/KG
IVN-RAT LD50: 80500 UG/KG
UNR-RAT LD50: 7 GM/KG
ORL-MUS LD50: 5130 MG/KG
IPR-MUS LD50: 3050 MG/KG
IVN-MUS LD50: 54500 UG/KG
IVN-DOG LD50: 63300 UG/KG
ORL-RBT LD50: 3500 MG/KG
SKN-RBT LD50: 8 GM/KG
ORL-GPG LD50: 4400 MG/KG

FCTOD7 26,475,88

ARZNAD 26,1581,76
ARZNAD 26,1581,76
IYKEDH 18,922,87
342IAG -,408,69
EPASR* 8EHQ-1087-0695
EPASR* 8EHQ-1087-0695
IYKEDH 18,922,87
IYKEDH 18,922,87
GISAAA 35(6),84,70
NPIRI* 1,84,74
GISAAA 35(6),84,70

REVIEWS, STANDARDS, AND REGULATIONS

NOHS 1974: HZD M1569; NIS 30; TNF 2458; NOS 43; TNE 25255
NOES 1983: HZD M1569000; TNF 63; NIS 3902; NOS 73; TNE 85169; TFE 23478

EPA TSCA CHEMICAL INVENTORY, JUNE 1990

EPA TSCA SECTION 8(E) STATUS REPORT 8EHQ-1087-0695

EPA TSCA TEST SUBMISSION (TSCATS) DATA BASE, MARCH 1991

NTP CARCINOGENESIS STUDIES; SELECTED, APRIL 1991

TARGET ORGAN DATA

EFFECTS ON FERTILITY (POST-IMPLANTATION MORTALITY)
SPECIFIC DEVELOPMENTAL ABNORMALITIES (CENTRAL NERVOUS SYSTEM)
SPECIFIC DEVELOPMENTAL ABNORMALITIES (MUSCULOSKELETAL SYSTEM)

ONLY SELECTED REGISTRY OF TOXIC EFFECTS OF CHEMICAL SUBSTANCES (RTECS)
DATA IS PRESENTED HERE. SEE ACTUAL ENTRY IN RTECS FOR COMPLETE INFORMATION.

CONTINUED ON NEXT PAGE

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M A T E R I A L S A F E T Y D A T A S H E E T PAGE 2

CUST#: 000000
PO#:

PRODUCT #: 59120
CAS #: 312-50-4
MF: C5H9NO

NAME: 1-METHYL-2-PYRROLIDONE

----- HEALTH HAZARD DATA -----

ACUTE EFFECTS

HARMFUL IF SWALLOWED, INHALED, OR ABSORBED THROUGH SKIN.
VAPOR OR MIST IS IRRITATING TO THE EYES, MUCOUS MEMBRANES AND UPPER
RESPIRATORY TRACT.
CAUSES SKIN IRRITATION.
PROLONGED EXPOSURE CAN CAUSE:
STOMACH PAINS, VOMITING, DIARRHEA.

CHRONIC EFFECTS

OVEREXPOSURE MAY CAUSE REPRODUCTIVE DISORDER(S) BASED ON TESTS WITH
LABORATORY ANIMALS.
TARGET ORGAN(S):
BONE MARROW
THYMUS
SPLEEN
LYMPHATIC SYSTEM

FIRST AID

IN CASE OF CONTACT, IMMEDIATELY FLUSH EYES OR SKIN WITH COPIOUS
AMOUNTS OF WATER FOR AT LEAST 15 MINUTES WHILE REMOVING CONTAMINATED
CLOTHING AND SHOES.
ASSURE ADEQUATE FLUSHING OF THE EYES BY SEPARATING THE EYELIDS
WITH FINGERS.
IF INHALED, REMOVE TO FRESH AIR. IF NOT BREATHING GIVE ARTIFICIAL
RESPIRATION. IF BREATHING IS DIFFICULT, GIVE OXYGEN.
IF SWALLOWED, WASH OUT MOUTH WITH WATER PROVIDED PERSON IS CONSCIOUS.
CALL A PHYSICIAN.
REMOVE AND WASH CONTAMINATED CLOTHING PROMPTLY.
DISCARD CONTAMINATED SHOES.

ADDITIONAL INFORMATION

RATS EXPOSED TO 1-METHYL-2-PYRROLIDINONE AT A CONCENTRATION OF 1 MG/L
AS AN AEROSOL FOR 10 DAYS SHOWED DEPLETION OF HEMATOPOIETIC CELLS IN
THE BONE MARROW AND ATROPHY OF THE LYMPHOID TISSUES OF THE THYMUS,
SPLEEN AND LYMPH NODES.

----- PHYSICAL DATA -----

BOILING PT: 202 C
MELTING PT: -24 C

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M A T E R I A L S A F E T Y D A T A S H E E T P A G E 3

CUST#: 000000
PO#:

PRODUCT #: 69120
CAS #: 872-50-4
MF: C5H9NO

NAME: 1-METHYL-2-PYRROLIDONE

----- PHYSICAL DATA -----

SPECIFIC GRAVITY: 1.026
VAPOR DENSITY: 3.4
VAPOR PRESSURE: .29 MM @ 20 C
 .99 MM @ 40 C
APPEARANCE AND ODOR
COLORLESS LIQUID

----- FIRE AND EXPLOSION HAZARD DATA -----

FLASHPOINT: 187 F
AUTOIGNITION TEMPERATURE: 518 F
LOWER EXPLOSION LEVEL: 1.3%
UPPER EXPLOSION LEVEL: 9.5%
EXTINGUISHING MEDIA
WATER SPRAY.
CARBON DIOXIDE, DRY CHEMICAL POWDER OR APPROPRIATE FOAM.
SPECIAL FIREFIGHTING PROCEDURES
WEAR SELF-CONTAINED BREATHING APPARATUS AND PROTECTIVE CLOTHING TO
PREVENT CONTACT WITH SKIN AND EYES.
COMBUSTIBLE LIQUID.
UNUSUAL FIRE AND EXPLOSIONS HAZARDS
EMITS TOXIC FUMES UNDER FIRE CONDITIONS.

----- REACTIVITY DATA -----

INCOMPATIBILITIES
STRONG ACIDS
STRONG OXIDIZING AGENTS
HAZARDOUS COMBUSTION OR DECOMPOSITION PRODUCTS
THERMAL DECOMPOSITION MAY PRODUCE CARBON MONOXIDE, CARBON DIOXIDE,
AND NITROGEN OXIDES.

----- SPILL OR LEAK PROCEDURES -----

STEPS TO BE TAKEN IF MATERIAL IS RELEASED OR SPILLED
EVACUATE AREA.
WEAR SELF-CONTAINED BREATHING APPARATUS, RUBBER BOOTS AND HEAVY---
RUBBER GLOVES.
ABSORB ON SAND OR VERMICULITE AND PLACE IN CLOSED CONTAINERS FOR

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M A T E R I A L S A F E T Y D A T A S H E E T PAGE 4

CUST#: 000000
PO#:

PRODUCT #: 69120
CAS #: 872-50-4
MF: C5H9NO

NAME: 1-METHYL-2-PYRROLIDONE

----- SPILL OR LEAK PROCEDURES -----

DISPOSAL.
VENTILATE AREA AND WASH SPILL SITE AFTER MATERIAL PICKUP IS COMPLETE.
WASTE DISPOSAL METHOD
THIS COMBUSTIBLE MATERIAL MAY BE BURNED IN A CHEMICAL INCINERATOR
EQUIPPED WITH AN AFTERBURNER AND SCRUBBER.

--- PRECAUTIONS TO BE TAKEN IN HANDLING AND STORAGE ---

CHEMICAL SAFETY GOGGLES.
SAFETY SHOWER AND EYE BATH.
NIOSH/MSHA-APPROVED RESPIRATOR.
USE ONLY IN A CHEMICAL FUME HOOD.
WEAR HEAVY RUBBER GLOVES.
DO NOT BREATHE VAPOR.
AVOID CONTACT WITH EYES, SKIN AND CLOTHING.
MAY BE READILY ABSORBED THROUGH SKIN.
WASH THOROUGHLY AFTER HANDLING.
IRRITANT.
POSSIBLE TERATOGEN.
KEEP TIGHTLY CLOSED.
KEEP AWAY FROM HEAT AND OPEN FLAME.
STORE IN A COOL DRY PLACE.
LABEL PRECAUTIONARY STATEMENTS
HARMFUL
HARMFUL BY INHALATION, IN CONTACT WITH SKIN AND IF SWALLOWED.
IRRITATING TO EYES, RESPIRATORY SYSTEM AND SKIN.
POSSIBLE RISK OF IRREVERSIBLE EFFECTS.
POSSIBLE TERATOGEN.
TARGET ORGAN(S):
BONE MARROW
THYMUS
COMBUSTIBLE.
HYGROSCOPIC
STORE UNDER NITROGEN.
IN CASE OF CONTACT WITH EYES, RINSE IMMEDIATELY WITH PLENTY OF
WATER AND SEEK MEDICAL ADVICE.
WEAR SUITABLE PROTECTIVE CLOTHING.
DO NOT BREATHE VAPOR.

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